

## The Simple Fuse

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### Summary

The fuse is perhaps the simplest component in used to protect many complex circuit boards or even systems. Yet, this is a key component for it has the task of limiting current draw and providing a margin of safety. The fuse may not be so simple to select, however, as there are up to nine criteria that might be considered when specifying what fuse to employ in a given situation. Many engineers may still have trouble selecting the best fuse for their own application because of conflicting requirements.

### Detail

The fuse is a series conductor whose sole purpose is to limit current flow. The current limit mode could be a slow rise from a steady state condition or it might be a high current transient. The fuse is a one-shot device, unlike most components. When a certain set of conditions occur, the fuse suddenly becomes electrically open and fails to conduct current. Treat this as bimodal operation. In the normal state the fuse has a very low resistance (5 to 40 milliohms) and looks like a conductor that connects one part of a circuit (typically an input) to another. The open mode is the second state of a fuse. The resistance appears greater than 100 Mega Ohms. What causes the fuse to open and when does it open?

The classical fuse is usually a simple small piece of metal often looking like a wire, though fuses exist on integrated circuits, there are fusible resistors, varistors can be used as transient suppressors and resettable fuses are usually non-metallic. These will not be considered here. There may be many failure modes for fuses. The RAC document FMD [1] provides the following modes and percentages. The fuse fails to open when expected (29.8%); the fuse is slow to open (25.5%); the fuse has opened with no cause given (22.7%); the fuse opened unexpectedly (14.3%) and mechanical failure of the fuse (3.5%).

Fuses have a current and voltage rating. Typical voltages are 32 V, 63 V, 125V, 250V and 600V. Fuse current ratings are typically numbers such as 1 Amp, 2.5 Amps, 5 Amps and 20 Amps. A variety of values exist and manufacturers can create fuses with almost any current rating. Fuses come in a variety of sizes and shapes and these will not be discussed here. Three basic types of fuses exist, a slo-blo, a normal fuse and a fast fuse. These refer to how quickly the fuse opens under high current load. Why worry about this? More on this later to make it clear.

What are the selection factors for a fuse? Simply stated they are:

- 1) Operating voltage
- 2) Normal operating current
- 3) Ambient operating temperature
- 4) Maximum expected overload current
- 5) Desired minimum time to open in a fault state
- 6) Number and types of transient pulses and current
- 7) Maximum voltage drop across a fuse
- 8) Size limitations, if any
- 9) Mounting method

Since most fuses are one-shot devices, when a fuse opens, it causes a circuit to shut down and requires a repair or replacement. Therefore nuisance failures are a problem. These are defined as a fuse opening under normal or acceptable operating conditions. Now the operating voltage of a fuse must be equal to or greater than the available circuit voltage. This includes transient conditions. The five voltage values mentioned above usually cover all common applications of AC and DC circuits since well over 90% of circuits operate at less than 100V. Now a 125V fuse will be acceptable on a 120VAC power line, so this covers most other applications. The normal operating current often selects the fuse rating. The rule of thumb is to derate a fuse by 25% to 50%. If a circuit has a continuous current draw of 12 Amps, then a fuse of between 16 Amps (25% derating) and 24 Amps (50% derating) might be selected. The next item is to look at the maximum current draw. The 12 Amps is continuous, but we may discover that upon start-up the circuit draws 16 amps to 18 amps for five to ten milliseconds. Something in the range of 20 to 24 Amp meets the derating and start-up surge. Next consider the operating temperature. The fuse is temperature-sensitive and should run at a surface temperature of less than 50C. If the operating conditions are above 60C, the fuse may exhibit premature failures or require extra cooling. There are also special current derating factors that apply for this situation. Sufficient cooling can also be an issue at altitude. This should also be considered when circuits or systems operate in thin air situations.

What happens if a fuse has an “overload condition”? This answer depends upon the size of the overload and this is a key fuse selection guide. Consider the following information for a fuse.

Current	12 Amps normal
Transient pulses	16 Amps start-up for 7 milliseconds
Operating Temp.	45C
Overload	occasional current draw of 22 Amps for 3 seconds

Will a 20 Amps fuse work in this circuit? The answer may be yes. Consider the following table which relates time to failure versus percent of load.

Table 1 – The Life versus Operating Current for a Normal Fuse

Rating of fuse	Time to failure	Operating Temperature
100% current	Infinite (many hours)	75C rise or less
135% current	One hour max.	None
200% current	2 minutes max.	None

The 20 Amp fuse we selected earlier will not blow open at 22 Amps continuous (110% of rating) for more than an hour. Even at 27 Amps, the fuse may take about an hour to open. It takes a continuous current draw of 40 Amps or more for the 20Amps fuse to fail in a short period of time. Meanwhile, a current draw of 30 Amps on a circuit board may cause an overheated part, an overheated circuit board metallic run or via or even smoke to be generated. Thus, we might conclude the 20 Amp fuse was sized wrong for the possible overload current. One solution is to select a faster-acting fuse. This can be accomplished by looking at the time-current curve of the manufacturer. There is a trade-off to be considered. We need look at the incidence of transient pulses as well the how often the occasional overload condition might occur. Consider the following circuit conditions: Four times a day on the average the circuit is subjected to transient pulses at 16 Amps. This may be because of a restart of the circuit or caused by a major load shift from minimum load to maximum load. What is the projected life of the fuse for this transient situation? Table 2 shows one simple relationship for normal fuses to transients. Each fuse should be investigated for this if it is thought to be a problem. Additional transient cycle models may be found in the literature [2].

Table 2 – Transient Conditions and Fuse Life

Surge conditions	Surge cycles to failure
22% of melt conditions	100,000 cycles
29% of melt conditions	10,000 cycles
38% of melt conditions	1000 cycles
48% of melt conditions	100 cycles

Determine the melt condition for the fuse and identify what fraction that the transient condition represents. We do this and estimate the transient is about 15% of the melt conditions. Thus, the life is longer than 100,000 transient cycles. At four cycles per day, this is more than 68 years. The 16 Amp and 7 millisecond transient will not limit the fuse life. What about the 22 Amp and 3 second transient? This occurs twice a year on the average. It represents a condition where a FPGA needs to be reprogrammed to update it. A quick calculation suggests this condition is about 40% of the melt integral. The life is about 567 reprogram cycles. At twice a year, this is a life of about 284 years. When combined with the transient on the start up, this reduces the fuse life to slightly less than 55 years against both of these transients if not limited by other events.

The message here is to select the fuse rating carefully with the selection based upon a more complete knowledge of the circuit functions and transients. The situation may need a more in-depth study. While not all nine criteria were considered here, there are situations where each becomes important. In our example there was a trade-off between the transient response and the overload protection. The transient response drives up the fuse rating while the overload response usually drives down the current rating. It is clear that between 100% and 200% of the fuse rating, the standard fuse response can be very slow. If this is not acceptable, then a fast-acting fuse might be selected, but the faster acting fuse may lead to nuisance failures from the transient conditions. The design engineer needs to select carefully and the reliability engineer should look at derating and transients. Often the full system operating and transient conditions may not be known at the start of the development program. The FPGA reprogram example shows how things can change after a fuse is initially selected. At times, the design engineer may discover that the fuse may not be the best protection device. Other protection methods exist. It is always better to determine what the best solution is during development than to discover a problem in the field.

### References

- [1] Reliability Analysis Center, *Failure Mode/Mechanism Distributions*, published by the RAC, Rome, New York, 1991.
- [2] Meng, X.Z., and Sloat, J.G.J., Reliability Concepts for Electronic Fuses, Science, Measurement and Technology, IEE proceedings, Vol. 144, issue 2, pp 87-92, March 1997.